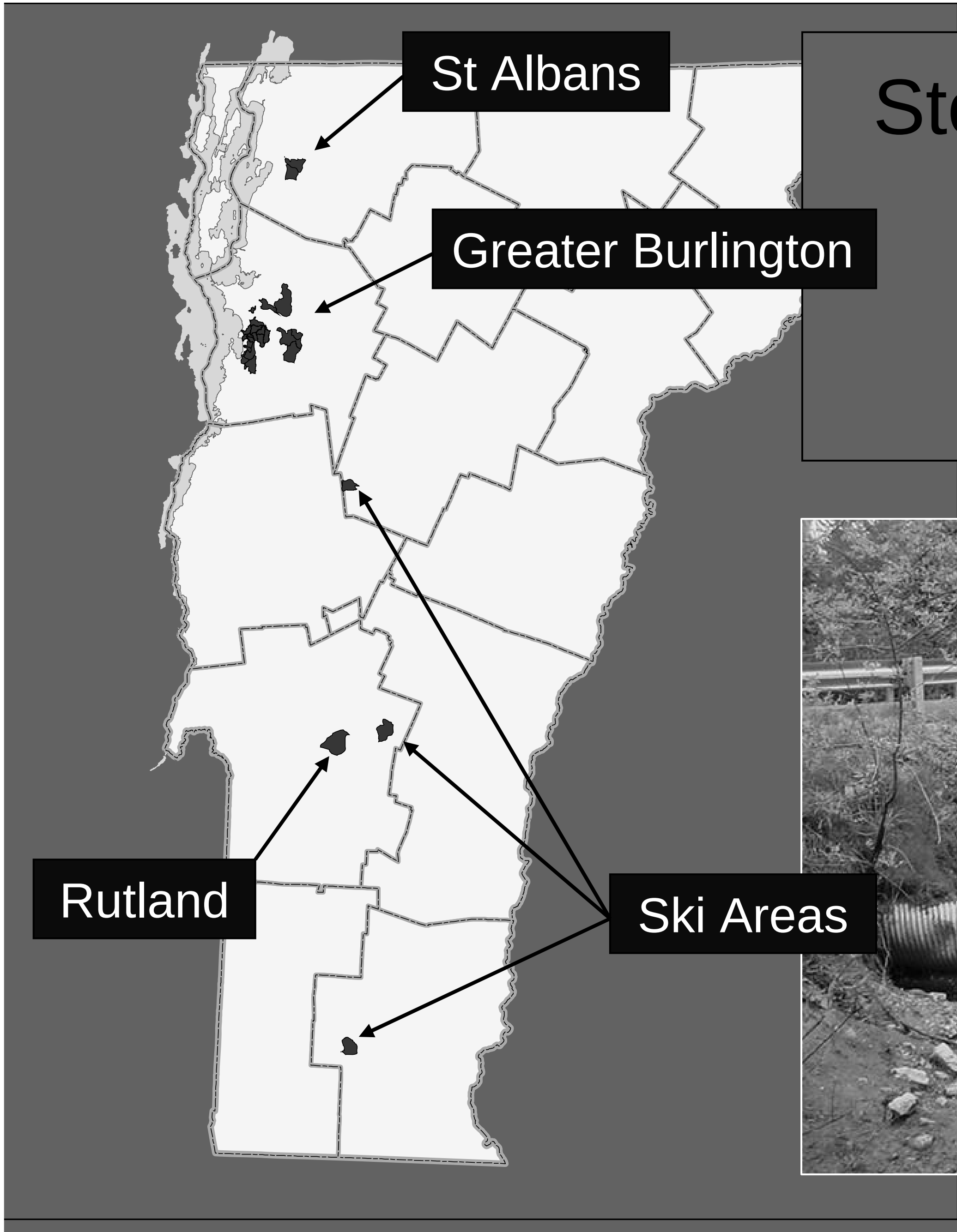
# Establishing Hydrologic-based Targets & Remediation Plans for Vermont's Stormwater Impaired Streams

Rick Hopkins – Vermont DEC
Tim Clear & Jen Callahan

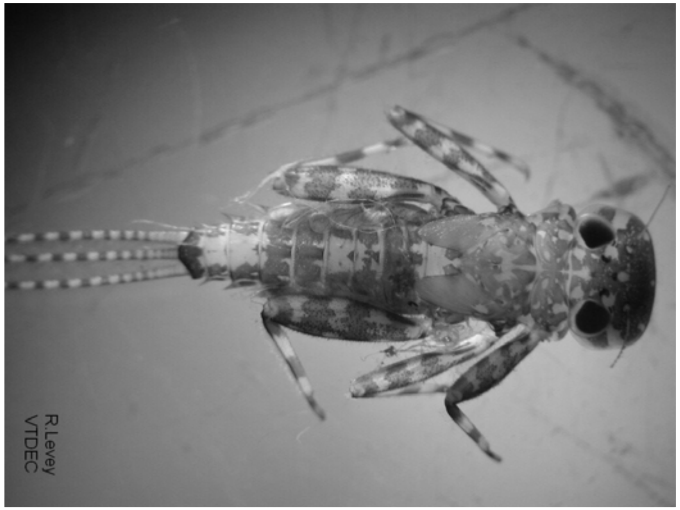
# Stormwater Impaired Watersheds:
# 12 Lowland
# 5 Mountain




# Impairment based on narrative aquatic life use criteria

- Macroinvertebrates
- Fish

Failure to meet minimum community criteria established for these stream types



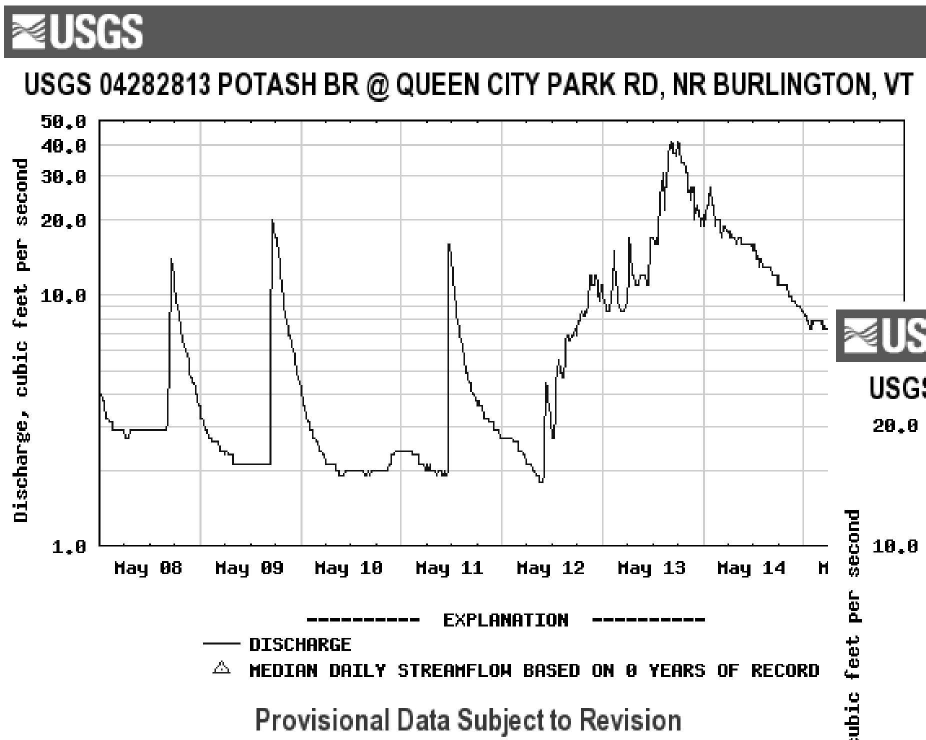

# Primary Stressors: Habitat Degradation & Sedimentation

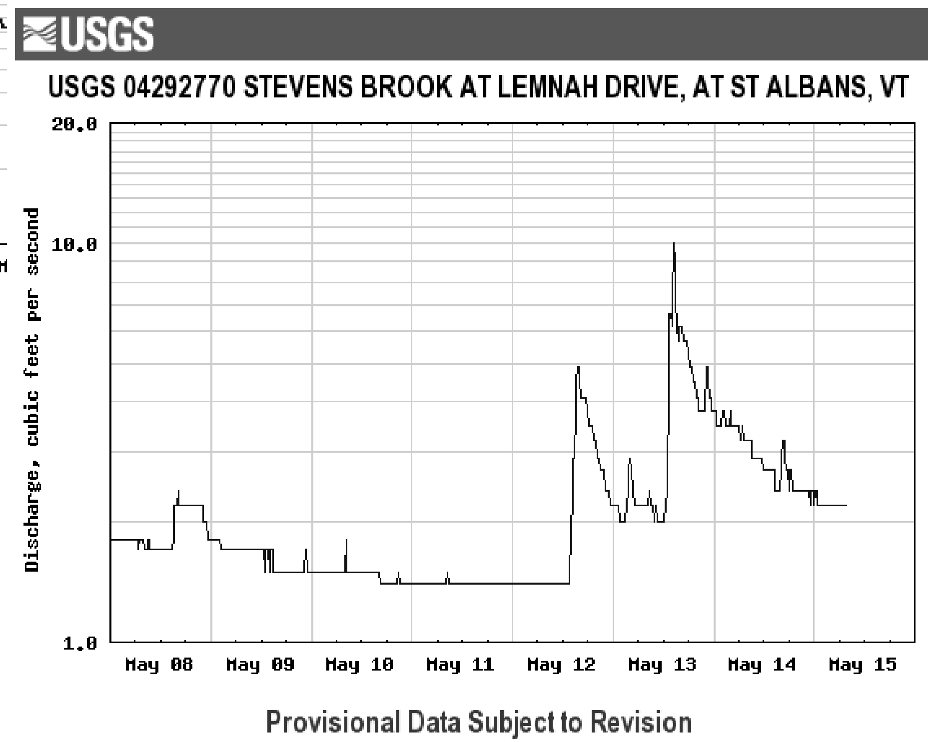
- Unbalanced substrate composition
  - Increased sand/silt
- Increased embeddedness
- Channel instability
  - Erosion, aggradation, degradation

# Primary Cause: Excess Stormwater Runoff

- Land use patterns
- Imperviousness
- Lack of stormwater treatment

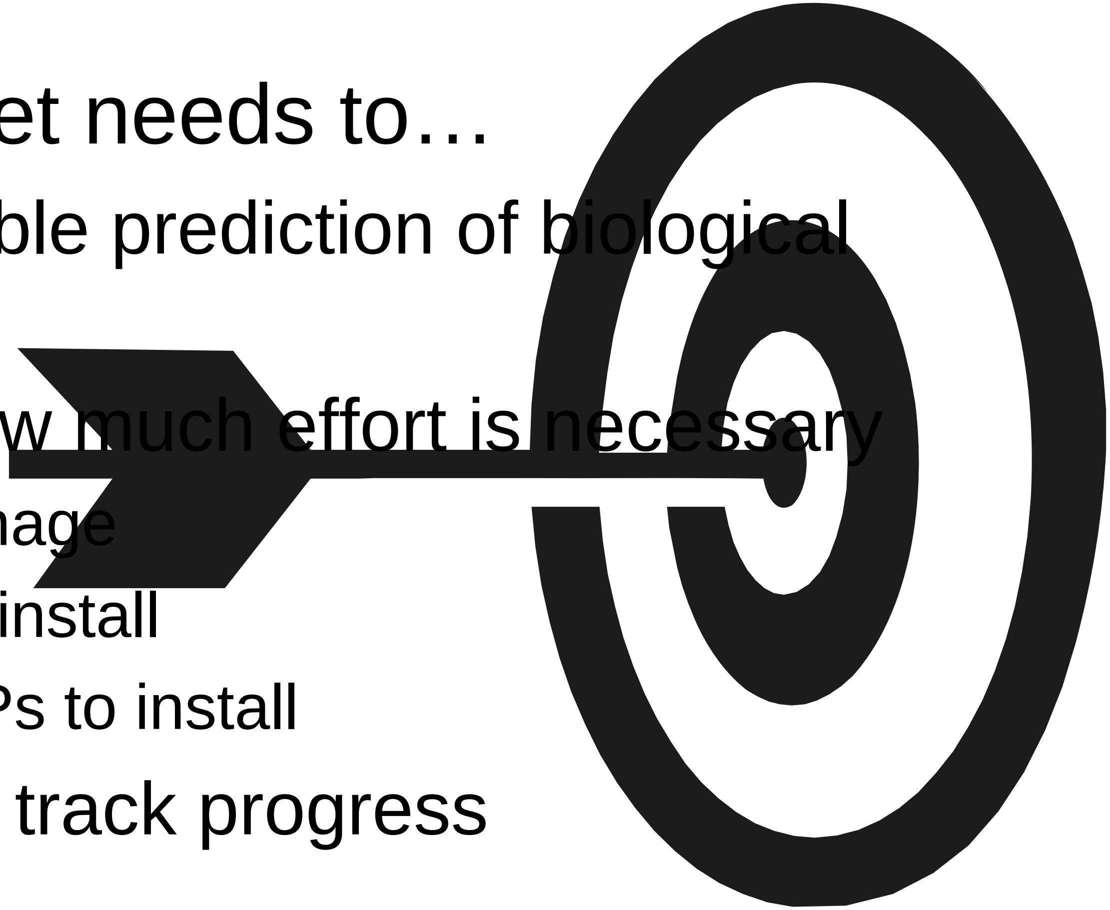
# Impaired Stream Hydrographs



# Remediation effort needs <u>surrogate target</u> for aquatic biota

- Surrogate target needs to…
  - allow reasonable prediction of biological response
  - help define how much effort is necessary
    - # sites to manage
    - # of BMPs to install
    - Types of BMPs to install
  - allow ability to track progress



# Sediment targets are problematic

- Washoff and instream sources
  - How much of each?
- Washoff estimates difficult:
  - Land use, topography, soils, climate
  - Data suggests extremely high variability
- Instream estimates difficult:
  - Bank and bed erosion
  - Complex instream sediment dynamics
  - Modeling/data intensive

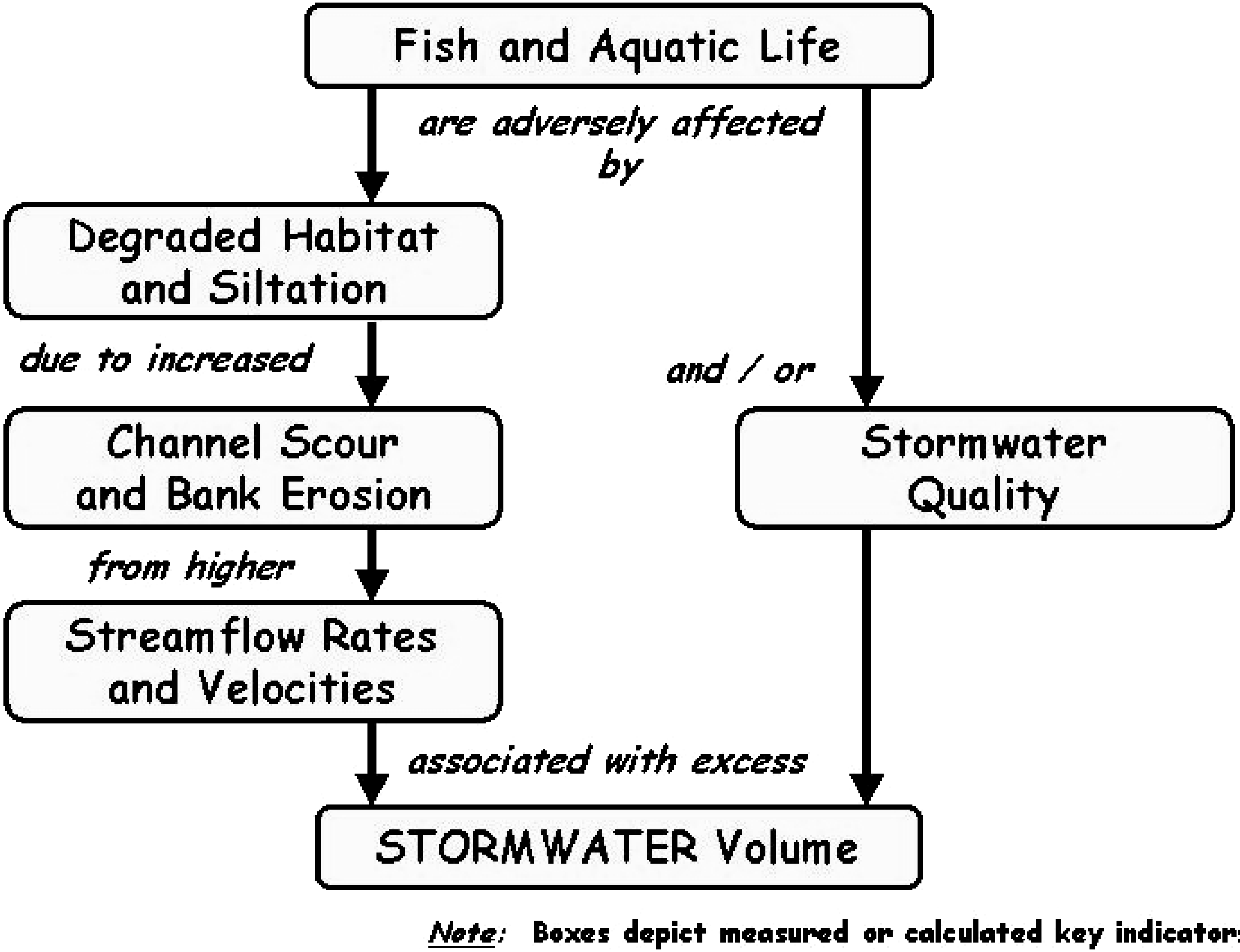
# Instream sediment

- Instream sources (bed/bank erosion) are the primary source of sediment
- Observational and SGA data
- Driven by hydrologic factors

# Hydrologic target

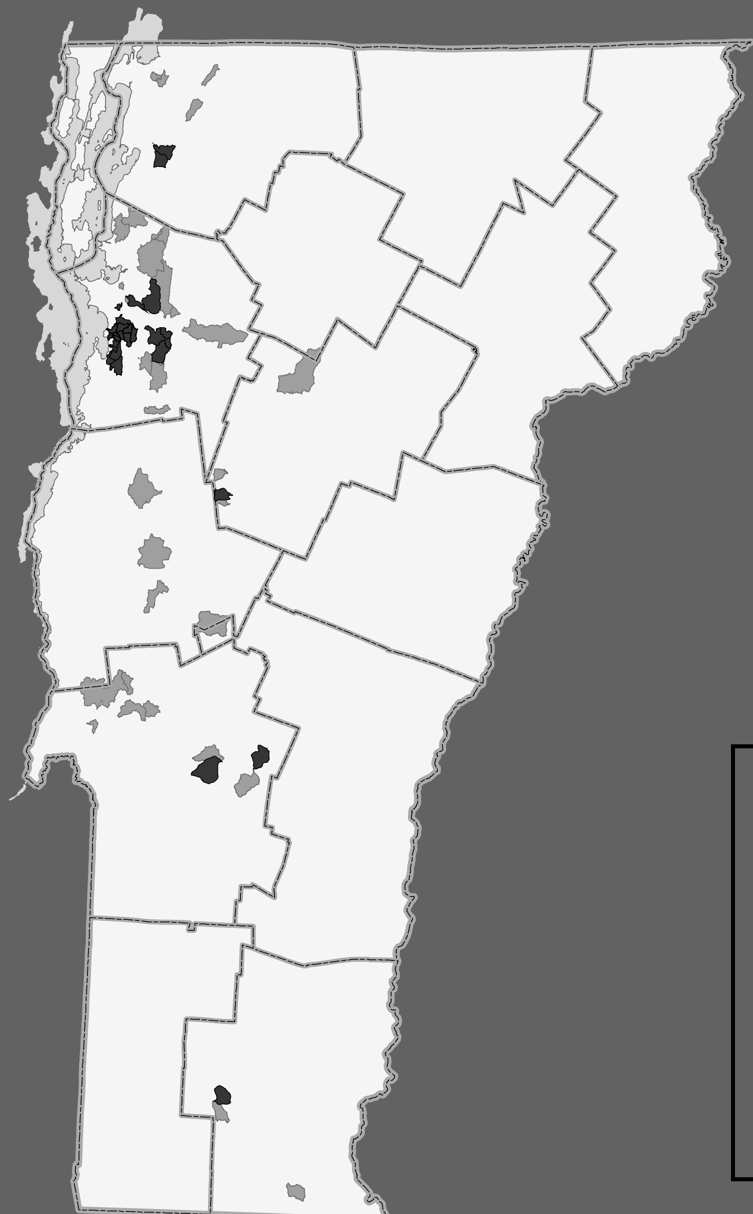
- Hydrologic regime drives sediment loading and habitat condition
- Better understanding of hydrologic responses in streams than sediment
- More predictability

# Hydrologic target rationale



# Attainment Watershed Approach

- Assumption: mimicking flow conditions in attainment watersheds will produce suitable and stable habitat in impaired watersheds
  - Develop targets based on flow characteristics of physically and geographically similar watersheds
- Lack of flow data requires hydrologic model simulation for all watersheds for comparison



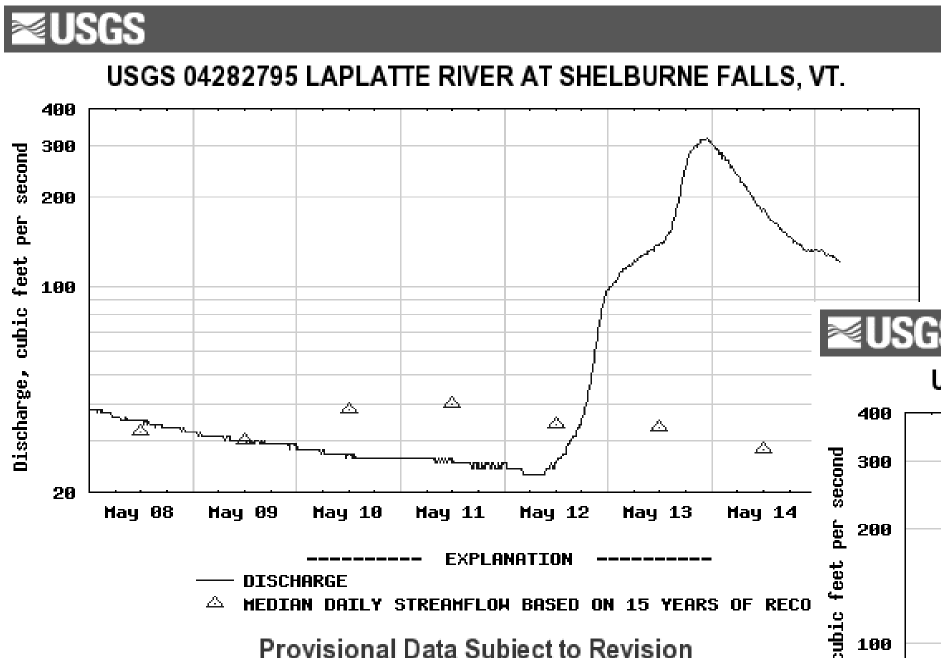
Attainment Streams

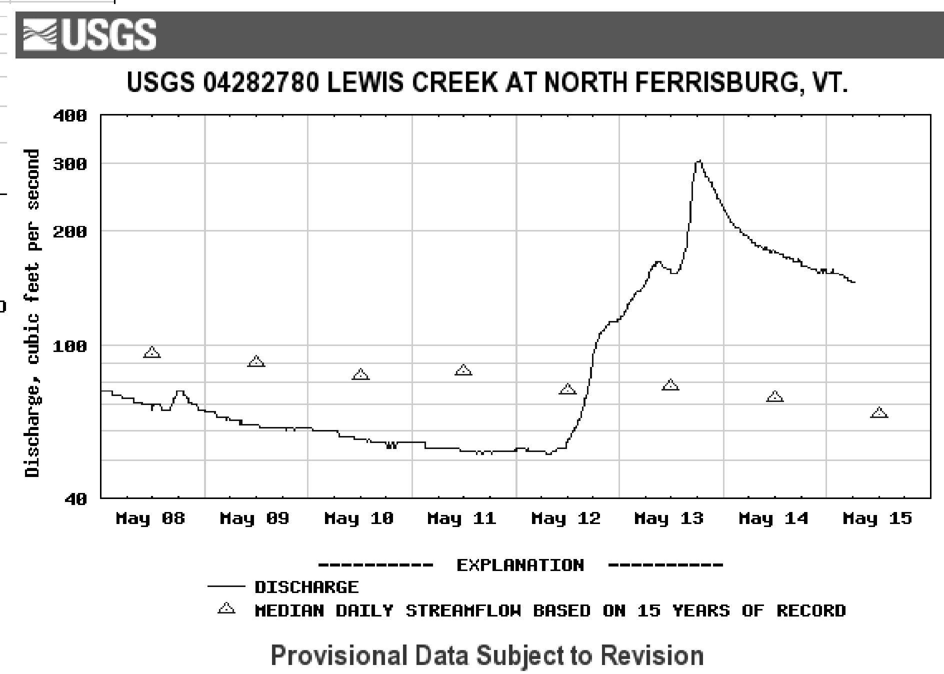
15 Lowland

6 Mountain

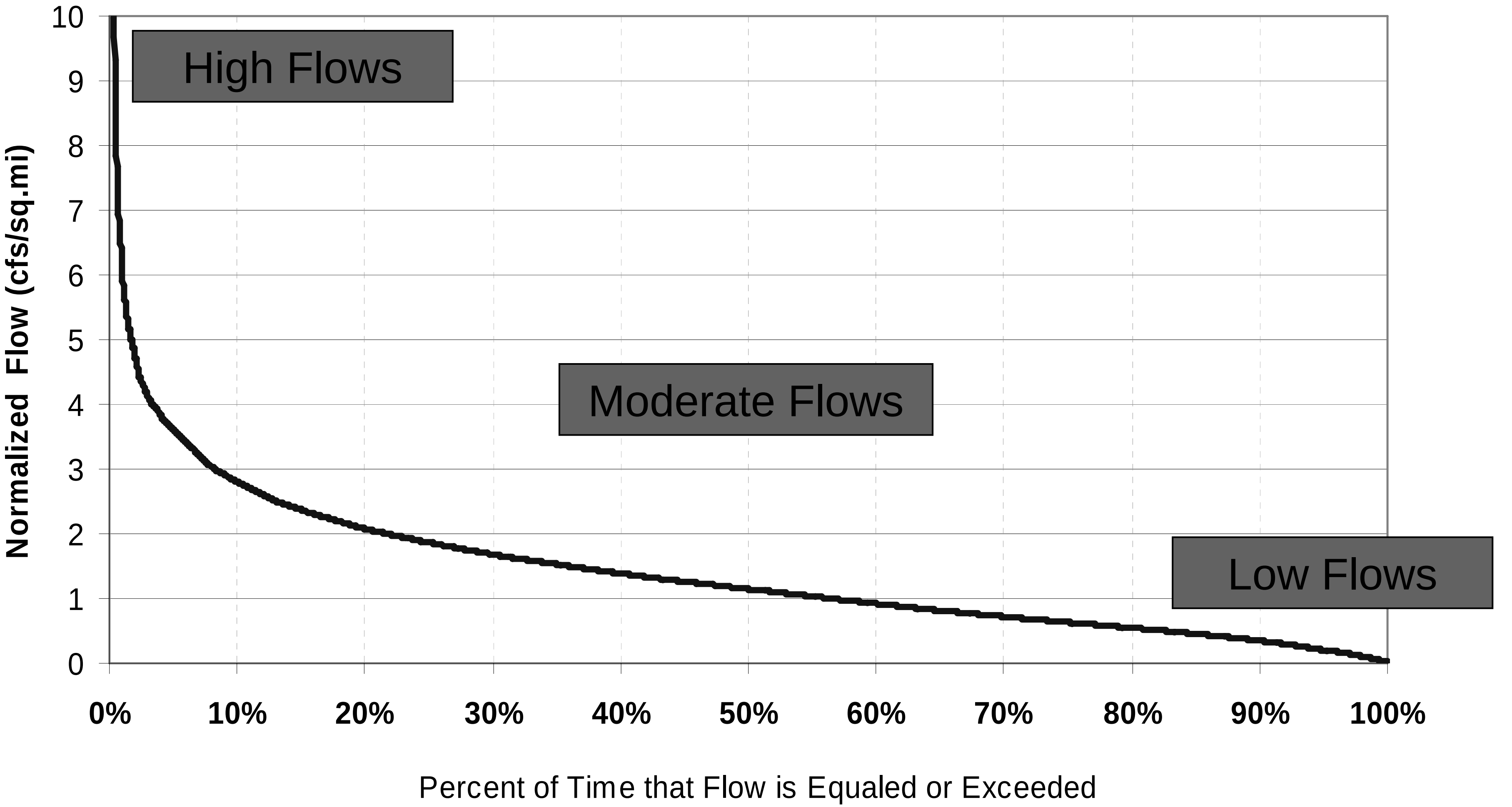
- Not “pristine” but biologically healthy
- Similar stream type
- Similar regions

# Attainment stream hydrographs



**Flow Duration Curve (FDC)** -- a cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.



# Targets on the FDC

- High flow: 0.3% approximately equals the one-day return flow. These flows have greatest impact on channel formation.

- Low flow: 95% approximately equals 7Q10 low flows. Decreased habitat for aquatic biota.

# Stormwater Modeling for Flow Duration Curve Development in Vermont

Tham Saravanapavan
Tetra Tech, Inc.

VERMONT DEPARTMENT OF ENVIRONMENTAL CONSERVATION

TETRA TECH, INC.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

# Model Selection

- Simulate hydrologic response of urban watershed
- Route flow and pollutants
- Model calibration
- Evaluate urban and mixed land uses and BMPs
- Available data, simplicity, budget and time, and expandability

# Why P8-UCM ?

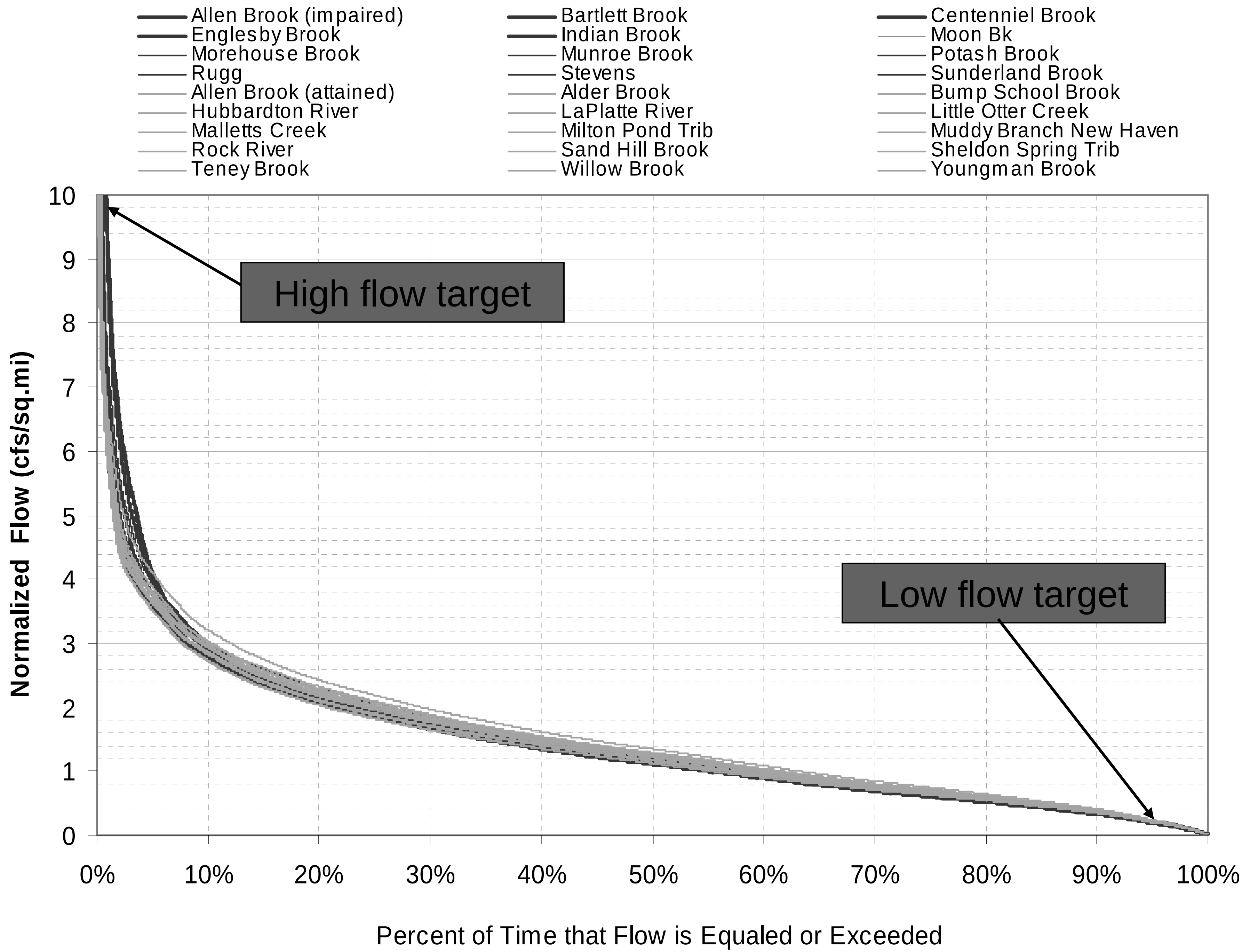
- Continuous simulation with hourly output
- Simulates snow melt
- Urban stormwater BMPs
- Data needs can be filled with available information
- Requires moderate effort to set up, calibrate, and apply
- Widely applied in New England

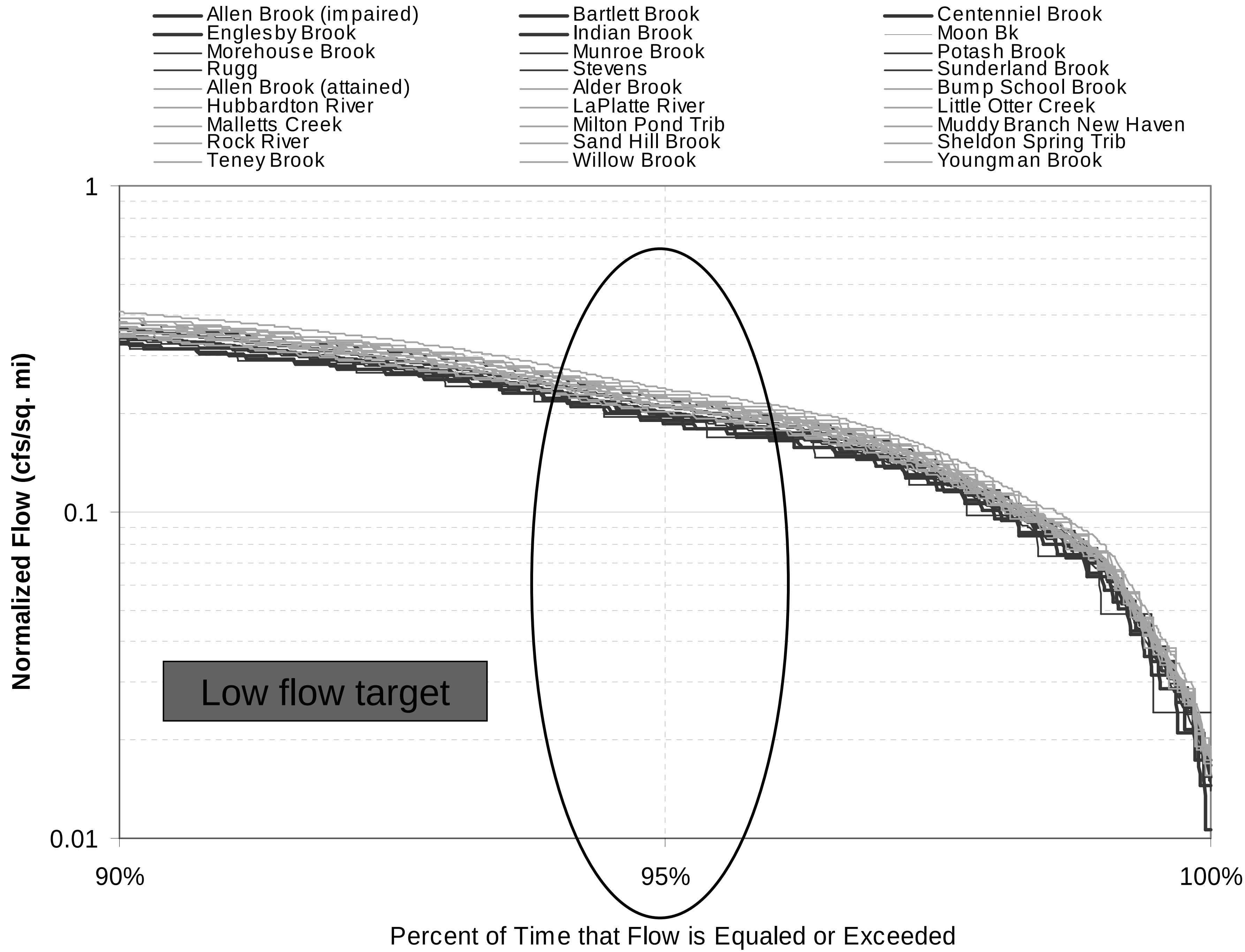
# P8 Model Inputs

- Watershed
  - Watershed Area
  - Pervious Curve Number (PCN)
  - Percent Imperviousness (PI)
  - Impervious Coefficient (IC)
  - Depression Storage
- Devices
  - Surface – Time of Concentration (TC-SR)
  - Ground – Time of Concentration (TC-BF)
  - Groundwater Enhancement – Simple Linear Reservoir Model
- Climate
  - Hourly Precipitation
  - Daily Temperature

# Model Calibration

- Initial Calibration Using USGS Daily Data
- Detailed Calibration Using UVM Hourly Data


Allen Brook (impaired)
Bartlett Brook
Centenniel Brook
Englesby Brook
Indian Brook
Moon Bk
Morehouse Brook
Munroe Brook
Potash Brook
Rugg
Stevens
Sunderland Brook
Allen Brook (attained)
Alder Brook
Bump School Brook
Hubbardton River
LaPlatte River
Little Otter Creek
Malletts Creek
Milton Pond Trib
Muddy Branch New Haven
Rock River
Sand Hill Brook
Sheldon Spring Trib
Teney Brook
Willow Brook
Youngman Brook
High flow target
Low flow target
Normalized Flow (cfs/sq.mi)
Percent of Time that Flow is Equaled or Exceeded
0
1
2
3
4
5
6
7
8
9
10
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%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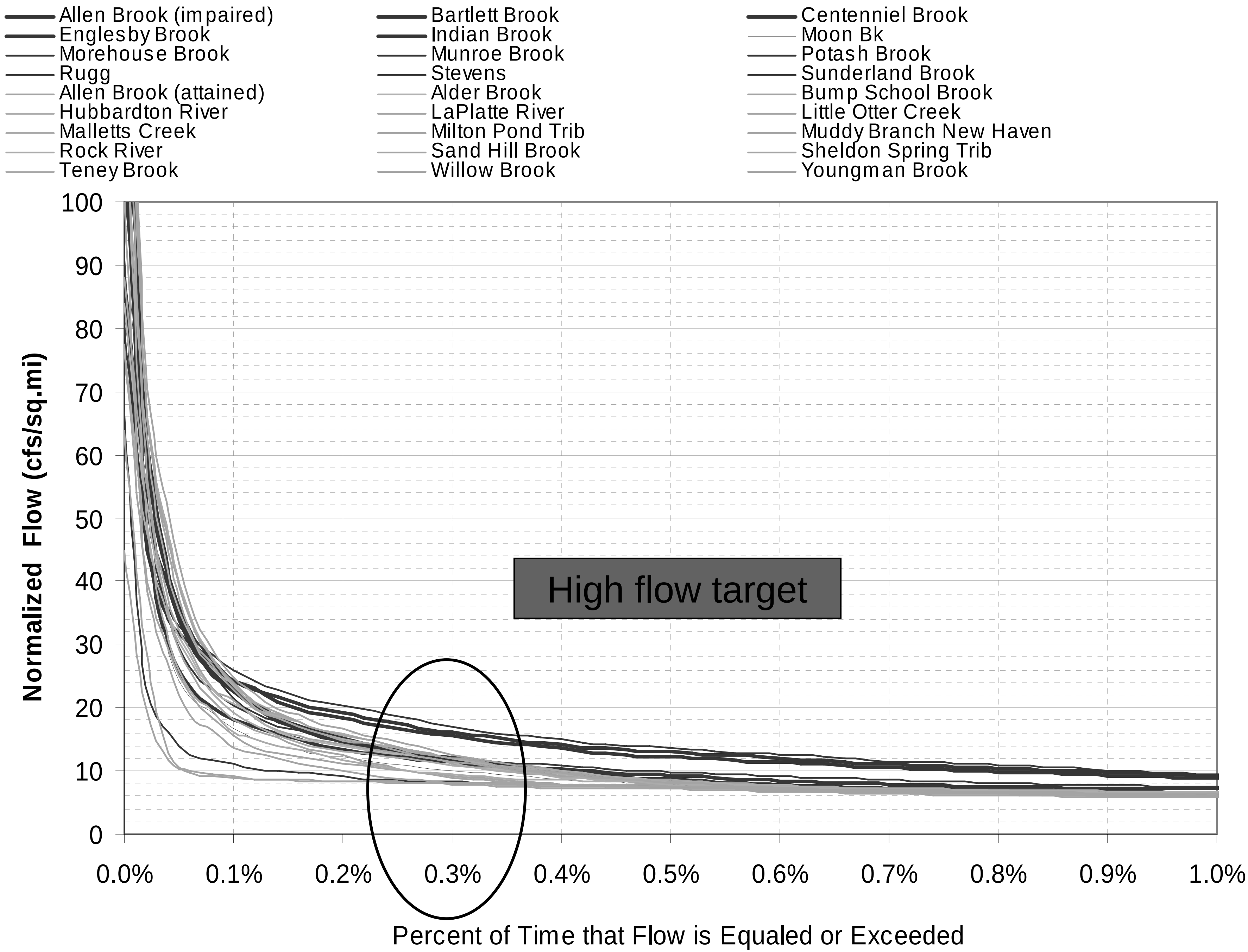
Milton Pond Trib
Muddy Branch New Haven
Rock River
Sand Hill Brook
Sheldon Spring Trib
Teney Brook
Willow Brook
Youngman Brook
1
0.1
0.01
Normalized Flow (cfs/sq. mi)
Low flow target
90%
95%
100%
Percent of Time that Flow is Equaled or Exceeded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Milton Pond Trib
Muddy Branch New Haven
Rock River
Sand Hill Brook
Sheldon Spring Trib
Teney Brook
Willow Brook
Youngman Brook
Normalized Flow (cfs/sq.mi)
100
90
80
70
60
50
40
30
20
10
0
High flow target
0.0%
0.1%
0.2%
0.3%
0.4%
0.5%
0.6%
0.7%
0.8%
0.9%
1.0%
Percent of Time that Flow is Equaled or Exceeded

# Statistical Analysis of Watershed Variables

Julie Foley & Dr. Breck Bowden
Rubenstein School of Environment and Natural Resources
University of Vermont

# Project Objectives

1. Identify which of the P-8 model input variables (land use, soils, slope, etc) explain the groupings between impaired and attainment watersheds.
2. Develop a statistically defensible method for matching attainment and impaired watersheds for target setting.

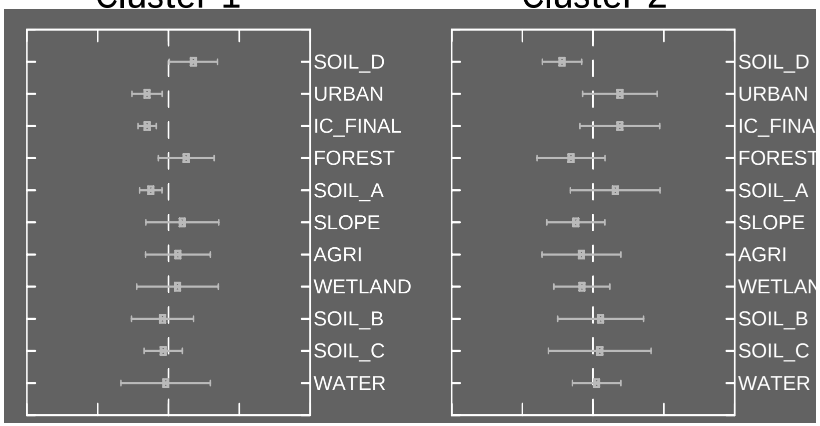
# Cluster Analysis

- Cluster analysis is a method used to identify natural groupings in datasets.
  - The most common use is when the number and members of groups in your data are not known.
  - Cluster analysis can also be used to see how members separate out when groupings are hypothesized.

# K-Means Two Cluster Analysis

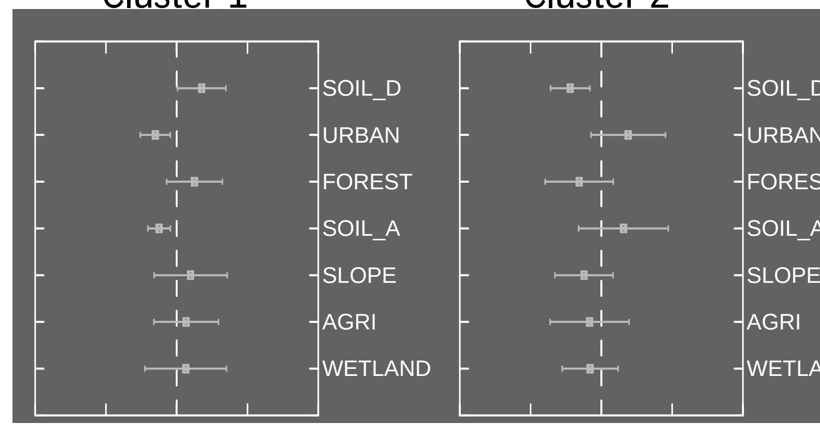
Preliminary Clusters

Cluster 1 Cluster 2




Final Clusters

Cluster 1 Cluster 2




**Note: Points on the graphs indicate the distance and relative value of the cluster mean from the total mean. The bars indicate the standard deviation of the mean within that cluster.**

- Preliminary clusters included all input variables, some with negligible differences in means.
- Final clusters included only the most influential watershed characteristics (Soil_D, Urban, Forest, etc.).

# K-Means Results

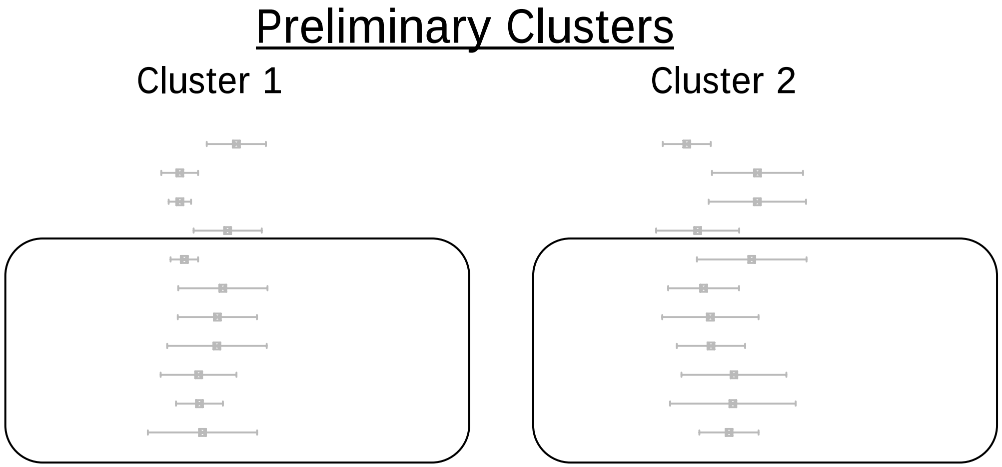
Watershed groupings based on the final k-Means clustering.

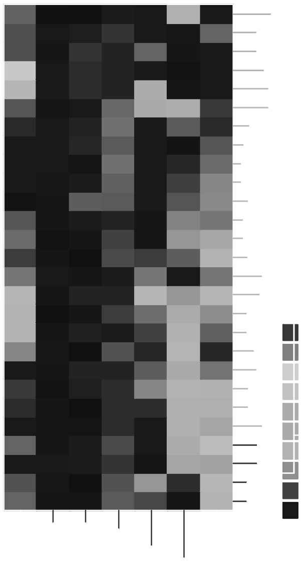
| Cluster 1 - 15 Cases | | |
|---|---|---|
| Case | Watershed | Status |
| 1 | Alder_A | A |
| 2 | Allen | A |
| 3 | BumpSchool | A |
| 4 | Hubbardton | A |
| 5 | Laplatte | A |
| 6 | LittleOtter | A |
| 7 | Malletts | A |
| 8 | MiltonPond | A |
| 9 | Muddy Branch | A |
| 10 | Rock | A |
| 12 | SheldonSpr | A |
| 14 | Willow | A |
| 16 | Allen_I | I |
| 20 | Indian | I |
| 23 | Munroe | I |

| Cluster 2 - 12 Cases | | |
|---|---|---|
| Case | Watershed | Status |
| 11 | SandHill | A |
| 13 | Teney | A |
| 15 | Youngman | A |
| 17 | Bartlett | I |
| 18 | Centennial | I |
| 19 | Englesby | I |
| 21 | Moon | I |
| 22 | Morehouse | I |
| 24 | Potash | I |
| 25 | Rugg | I |
| 26 | Stevens | I |
| 27 | Sunderland | I |

**Note the predominance of attainment watersheds in Cluster 1 and the predominance of impaired watersheds in Cluster 2.**

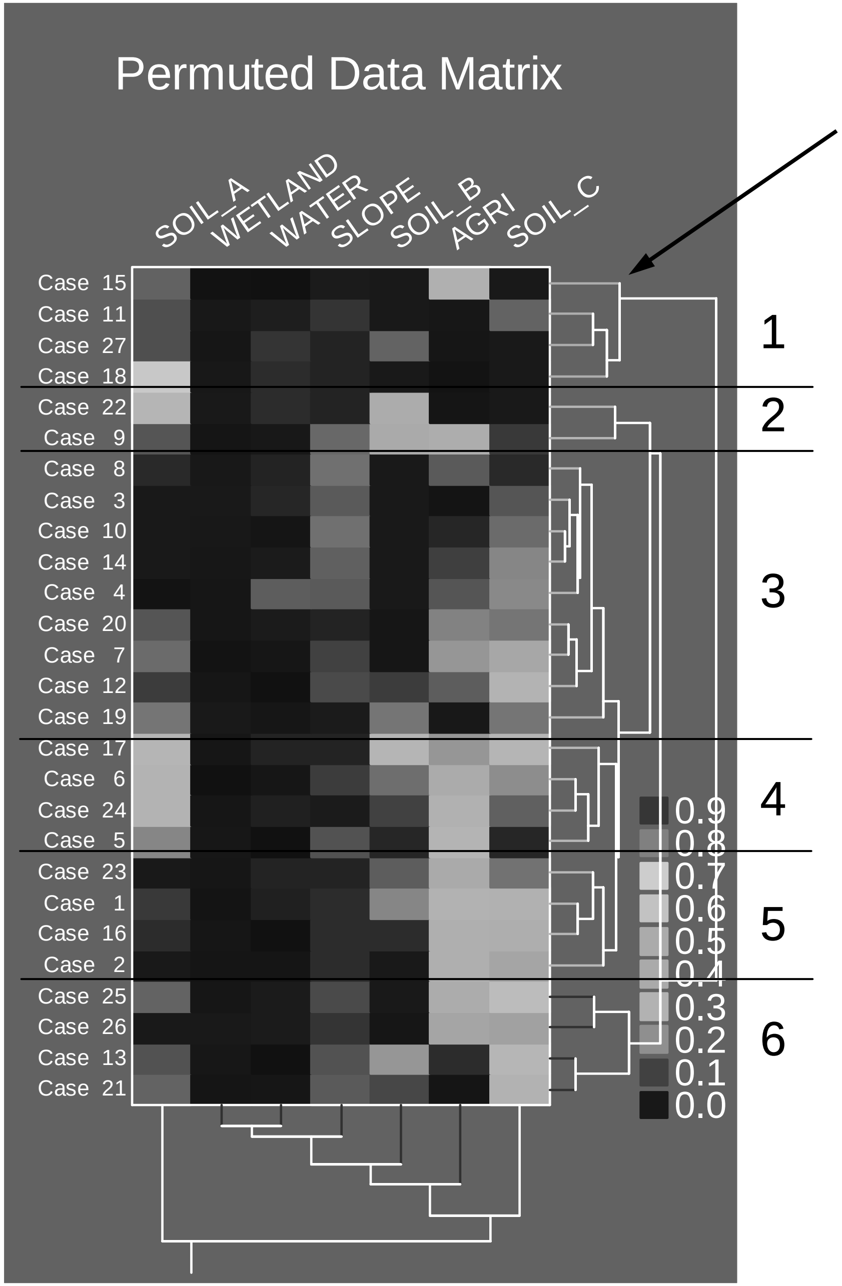
# Hierarchical Cluster Analysis



- Based on the *least* influential watershed characteristics.
- Resulted in better within-cluster mixing of attainment and impaired watersheds.

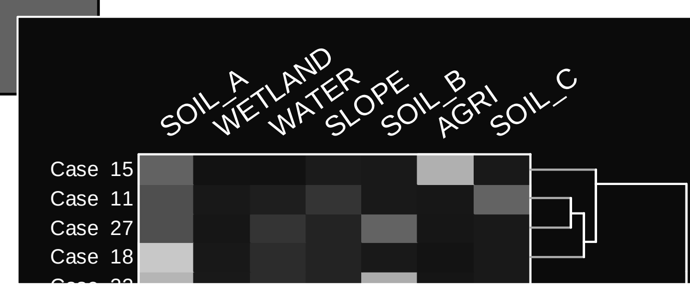
- Hierarchical Cluster Results:
  - We left Area, IC, Urban, Forest and Soil_D out of the hierarchical analysis as they have the most influence on watershed flow status.
  - The result is a good comparison of watershed characteristics regardless of flow influences.
  - Soil_A, Soil_C and Agri appear to have the most influence on clustering.
  - Groups of watersheds cluster on the basis of one or more watershed characteristic, ie. Soil_A.



# Setting Targets

- Mean attainment flow values for Q 0.3% and Q 95% flows are identified for each cluster.
- These means could be potential flow targets for the corresponding impairment watersheds.

| Watershed | Status | Q 0.3% | Avg A Q 0.3% | Std Dev | Q0.3% + SD |
|---|---|---|---|---|---|
| Centennial | I | 16.0399 | | | |
| Sunderland | I | 8.2525 | | | |
| SandHill | A | 8.0236 | 7.9636 | 0.0849 | 8.0485 |
| Youngman | A | 7.9035 | | | |



# Hierarchical Results – Q 0.3%

| Cluster | Case # | Watershed | Status | Q 0.3% | Avg A Q 0.3% | Std Dev | Q0.3% + SD |
|---|---|---|---|---|---|---|---|
| 1 | 18 | Centennial | I | 16.0399 | 7.9636 | 0.0849 | 8.0485 |
| | 27 | Sunderland | I | 8.2525 | | | |
| | 11 | SandHill | A | 8.0236 | | | |
| | 15 | Youngman | A | 7.9035 | | | |
| 2 | 22 | Morehouse | I | 16.8777 | 8.1448 | -- | - |
| | 9 | Muddy Branch | A | 8.1448 | | | |
| 3 | 19 | Englesby | I | 15.4649 | 11.5276 | 1.1173 | 12.6449 |
| | 20 | Indian | I | 11.6373 | | | |
| | 3 | BumpSchool | A | 12.5317 | | | |
| | 4 | Hubbardton | A | 11.9623 | | | |
| | 7 | Malletts | A | 10.9241 | | | |
| | 8 | MiltonPond | A | 12.0885 | | | |
| | 10 | Rock | A | 11.9923 | | | |
| | 12 | SheldonSpr | A | 9.2432 | | | |
| | 14 | Willow | A | 11.9511 | | | |
| 4 | 17 | Bartlett | I | 11.3478 | 10.2719 | 1.7680 | 12.0399 |
| | 24 | Potash | I | 12.2374 | | | |
| | 5 | Laplatte | A | 11.5221 | | | |
| | 6 | LittleOtter | A | 9.0217 | | | |
| 5 | 16 | Allen_I | I | 11.7358 | 11.2695 | 0.0912 | 11.3607 |
| | 23 | Munroe | I | 12.0108 | | | |
| | 1 | Alder | A | 11.3340 | | | |
| | 2 | Allen_A | A | 11.2050 | | | |
| 6 | 21 | Moon | I | 9.9587 | 9.3369 | -- | - |
| | 25 | Rugg | I | 11.3195 | | | |
| | 26 | Stevens | I | 11.9120 | | | |
| | 13 | Teney | A | 9.3369 | | | |

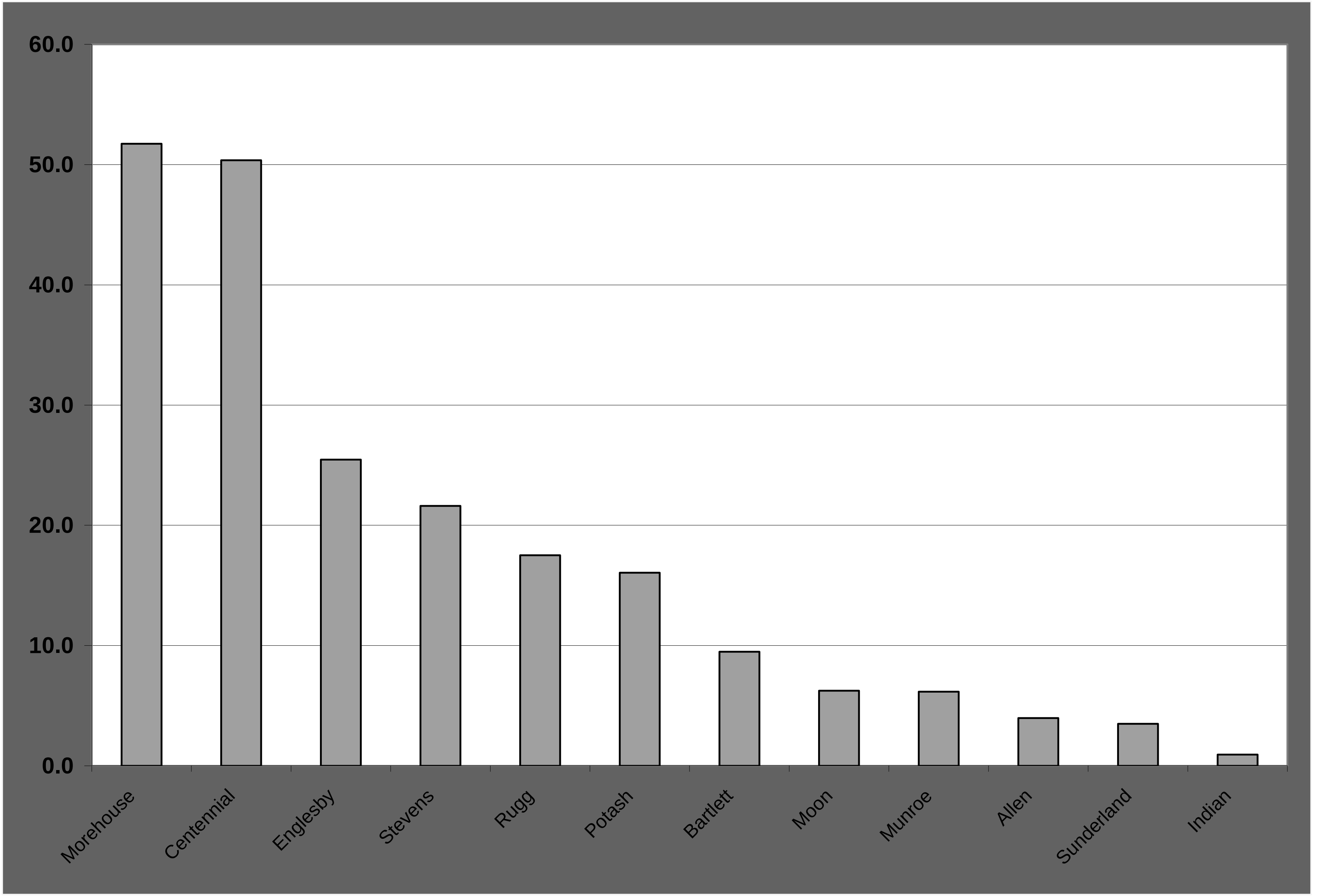
Q 95% flow exceeds or Q 0.3% flow is below the attainment average.

Q 95% flow exceeds or Q 0.3% flow is below the attainment average with standard deviation.

# Targets as percentages

- Model may lack some accuracy, but…
- Applied similarly across all watersheds so differences are relative
- Example:  Potash Brook
  - Q 0.3%: 1.9655/12.2374 = 16% reduction
  - Q 95%: 0.0226/0.1964 = 12% increase

# Percent reductions to meet targets



# Hierarchical Results - Q 95%

| Cluster | Case # | Watershed | Status | Q 95% | Avg A Q 95% | Std Dev | Q95% - SD |
|---|---|---|---|---|---|---|---|
| 1 | 18 | Centennial | I | 0.1875 | 0.2310 | 0.0035 | 0.2275 |
| | 27 | Sunderland | I | 0.2229 | | | |
| | 11 | SandHill | A | 0.2335 | | | |
| | 15 | Youngman | A | 0.2285 | | | |
| 2 | 22 | Morehouse | I | 0.1948 | 0.2176 | -- | - |
| | 9 | Muddy Branch | A | 0.2176 | | | |
| 3 | 19 | Englesby | I | 0.1903 | 0.2116 | 0.0074 | 0.2042 |
| | 20 | Indian | I | 0.2108 | | | |
| | 3 | BumpSchool | A | 0.2100 | | | |
| | 4 | Hubbardton | A | 0.2116 | | | |
| | 7 | Malletts | A | 0.2177 | | | |
| | 8 | MiltonPond | A | 0.2027 | | | |
| | 10 | Rock | A | 0.2036 | | | |
| | 12 | SheldonSpr | A | 0.2239 | | | |
| | 14 | Willow | A | 0.2121 | | | |
| 4 | 17 | Bartlett | I | 0.2000 | 0.2190 | 0.0083 | 0.2107 |
| | 24 | Potash | I | 0.1964 | | | |
| | 5 | Laplatte | A | 0.2132 | | | |
| | 6 | LittleOtter | A | 0.2249 | | | |
| 5 | 16 | Allen_I | I | 0.2015 | 0.2206 | 0.0048 | 0.2158 |
| | 23 | Munroe | I | 0.2016 | | | |
| | 1 | Alder | A | 0.2240 | | | |
| | 2 | Allen_A | A | 0.2172 | | | |
| 6 | 21 | Moon | I | 0.2030 | 0.2399 | -- | - |
| | 25 | Rugg | I | 0.2027 | | | |
| | 26 | Stevens | I | 0.1977 | | | |
| | 13 | Teney | A | 0.2399 | | | |

Q 95% flow exceeds or Q 0.3% flow is below the attainment average.

Q 95% flow exceeds or Q 0.3% flow is below the attainment average with standard deviation.

# Reaching the targets…

- Develop tools to predict stream hydrology in response to various BMPs
- Develop watershed specific stormwater permits based on hydrologic targets
- Monitor
  – Implementation
  – Instream hydrology
  – Aquatic life

1. Develop tool to predict stream hydrology in response to BMPs:

   - BMP Decision Support System for Evaluating Watershed-Wide Stormwater Management Alternatives (currently being developed)
     - Predict outcomes
     - Track progress

   - Data Collection
     - Subwatershed delineation/outfall mapping
     - Stream Geomorphic Assessment
     - Impervious surface mapping
     - Stream flow and precipitation monitoring
     - BMP Assessment

# Mapping Watersheds in Vermont's Stormwater Impaired Waterbodies

Pioneer Environmental Associates, LLC

R J TURNER COMPANY
656 VT Rte 17 Bristol, VT 05443

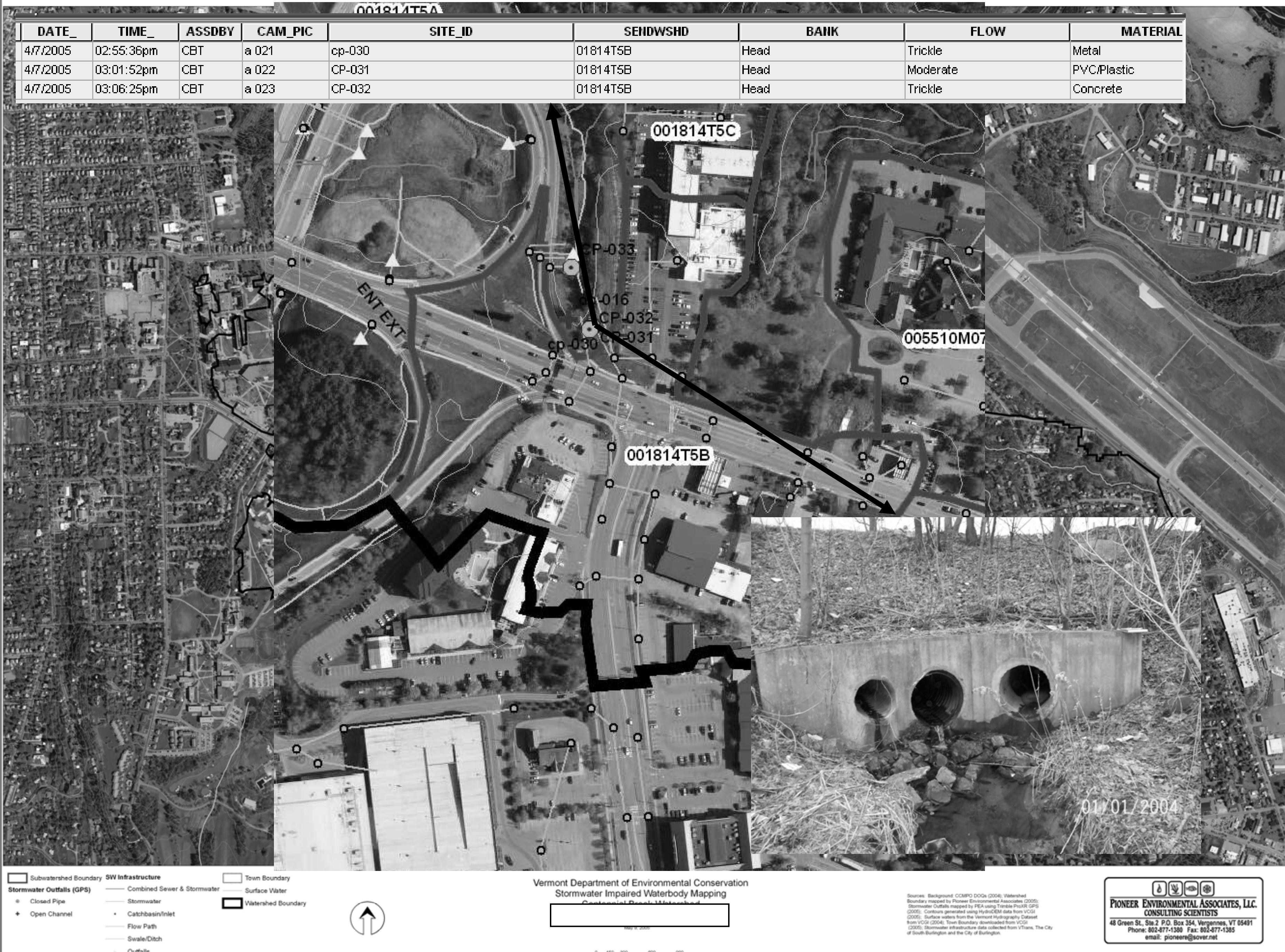
PIONEER ENVIRONMENTAL ASSOCIATES, LLC.
CONSULTING SCIENTISTS

VCGI INC.

# Subwatershed Mapping

- Map stormwater outfall locations and delineate watersheds for the 17 stormwater impaired waterbodies in Vermont
  - Record stormwater outfall locations and attribute data with GPS
  - Refine watershed boundaries, and delineate subwatersheds and stormwater catchments
  - Create updated maps of the stormwater impaired watersheds based on ground conditions in early 2005

| DATE_ | TIME_ | ASSDBY | CAM_PIC | SITE_ID | SENDWSHD | BANK | FLOW | MATERIAL |
|---|---|---|---|---|---|---|---|---|
| 4/7/2005 | 02:55:36pm | CBT | a 021 | cp-030 | 01814T5B | Head | Trickle | Metal |
| 4/7/2005 | 03:01:52pm | CBT | a 022 | CP-031 | 01814T5B | Head | Moderate | PVC/Plastic |
| 4/7/2005 | 03:06:25pm | CBT | a 023 | CP-032 | 01814T5B | Head | Trickle | Concrete |




Vermont Department of Environmental Conservation
Stormwater Impaired Waterbody Mapping
Centennial Brook Watershed

Sources: Background: CCMPO DOQs (2004); Watershed Boundary mapped by Pioneer Environmental Associates (2005); Stormwater Outfalls mapped by PEA using Trimble ProXR GPS (2005); Contours generated using HydroDEM data from VCGI (2005); Surface waters from the Vermont Hydrography Dataset from VCGI (2004); Town Boundary downloaded from VCGI (2005); Stormwater infrastructure data collected from VTrans, The City of South Burlington and the City of Burlington.


PIONEER ENVIRONMENTAL ASSOCIATES, LLC.
CONSULTING SCIENTISTS
48 Green St., Ste.2 P.O. Box 354, Vergennes, VT 05491
Phone: 802-877-1380 Fax: 802-877-1385
email: pioneere@sover.net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# Watershed Mapping Highlights

- To date, nearly 1600 outfall features captured by GPS and over 880 sub-watersheds delineated
- Local governments and other stakeholders have been included in the watershed mapping review process
- Watershed mapping has been updated to reflect operational stormwater discharge permit plans and other infrastructure data
- (Chittenden County) high-resolution elevation data (LIDAR) from Summer 2004 used to aid watershed mapping

# Vermont Stream Geomorphic Assessment (SGA) Protocols:

- Scientifically sound, reproducible data collection protocol
- Understandable to lay people, that informs rather than just advises
- Promotes sound land use practices and planning at the watershed scale
- Creates a database system (DMS) for users inside and outside the Agency of Natural Resources

# Three Phases of VT SGA:

**Phase I – GIS data gathering and SGAT (ArcView ext.)**

**Phase II – Rapid Stream Assessment (incl. RGA & RHA)**

Phase III – Detailed Reach Survey for Restoration Purposes

# Why Focus on Geomorphology in the Context of Stormwater Management?

- Holistic watershed-based approach for understanding PROCESSES occurring
- Assessment of stream channel sensitivity to current and future human impacts
- Baseline data
- Help to inform best placement of BMPs

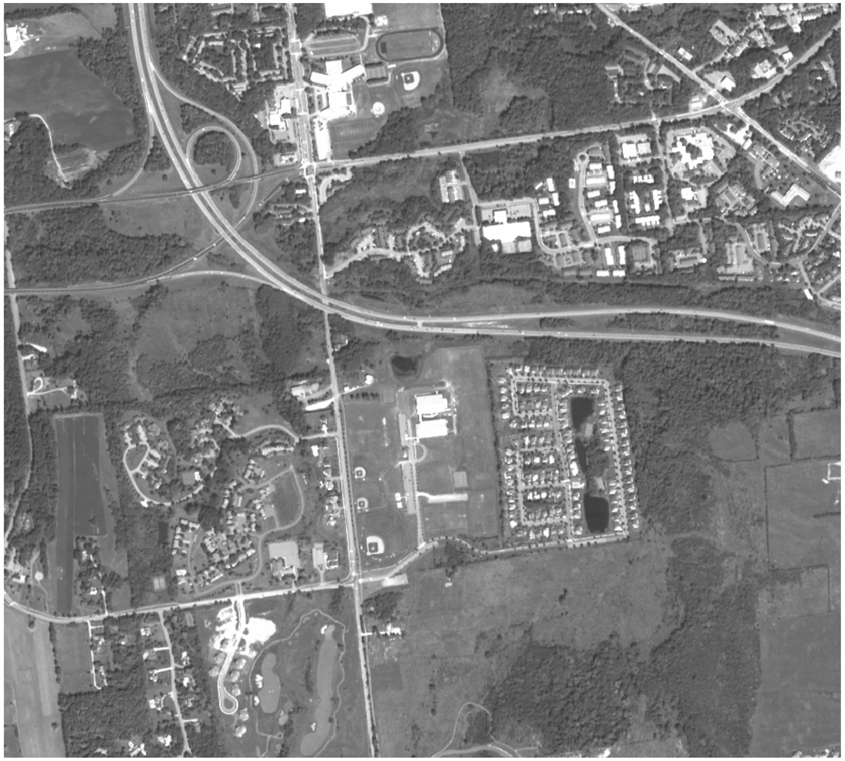
# Impervious Area Mapping QuickBird Multispectral and Panchromatic Data

Leslie A. Morrissey, Ph.D.
(RSENR/UVM)

2.4m Multispectral

0.6m Panchromatic

Imagery courtesy of Digital Globe



Original Image

NDVI

Impervious Threshold

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

# Impervious Area by Watershed


# Impervious Area of Impaired Watersheds

**Morehouse Brook (32%)**

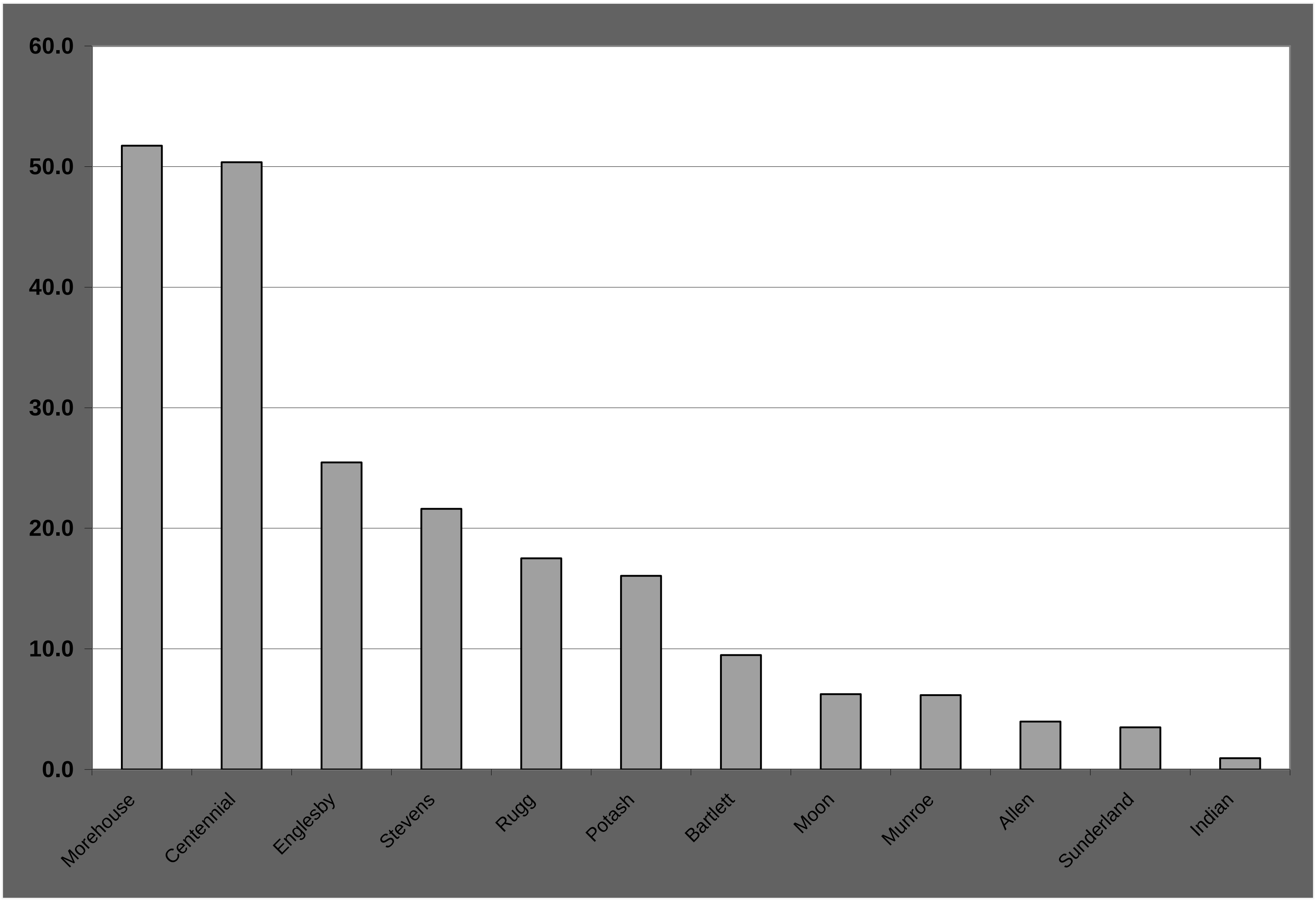
**Centennial Brook (31%)**

**Englesby Brook (27%)**

**Potash Brook (22%)**

**Bartlett Brook (17%)**

# Percent reductions to meet targets



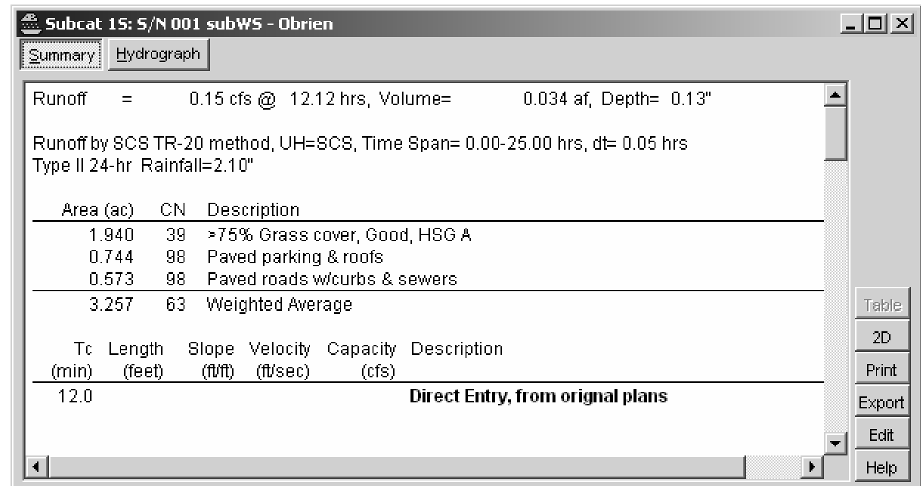
# Stream Flow and Precipitation Gauging

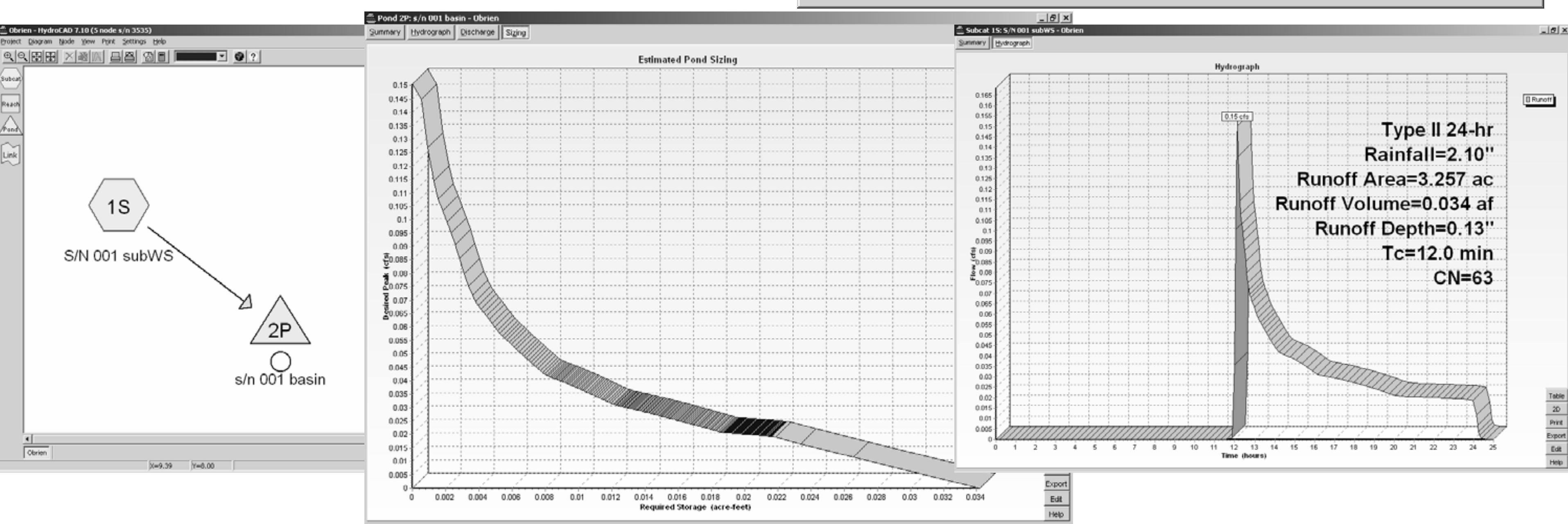
- Spring 2005 through Fall 2008
- Objective
  - Obtain baseline stream flow data in all stormwater impaired streams and some attainment streams

# Stormwater Pond Assessment

- Permit information on file varies greatly depending on age of permit
- Collected data for all permitted and significant stormwater detention structures
- Field checked all information
- Conducted limited Engineering Feasibility Analysis (EFA)

- Pond Information in Hydrocad
  - Size & Volume
  - Outlet Structure
  - Detention Time
  - Maintenance Issues
- Data incorporated into P8 model



# Putting it together

# Subwatersheds

# Pervious Curve Number

# Stormwater Ponds

# Quickbird

# SAWS

Spatial Analysis of Watershed Sensitivity

- "Ranks" subwatersheds based on watershed specific data
- Will be integrated into the Vermont BMP DSS

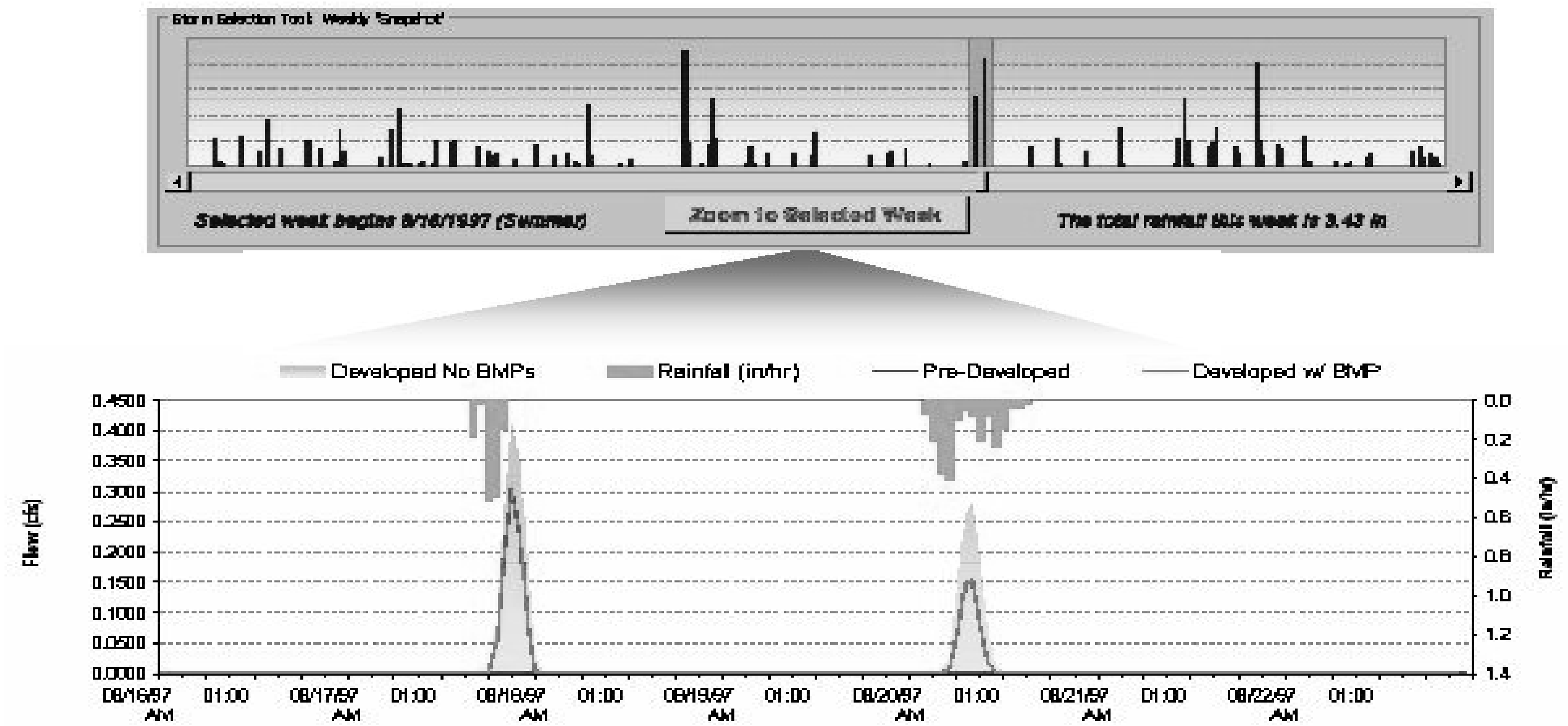
# SAWS Results

# Stormwater BMP Decision Support System for Vermont

*Currently under development by:*

Tetra Tech, Inc.

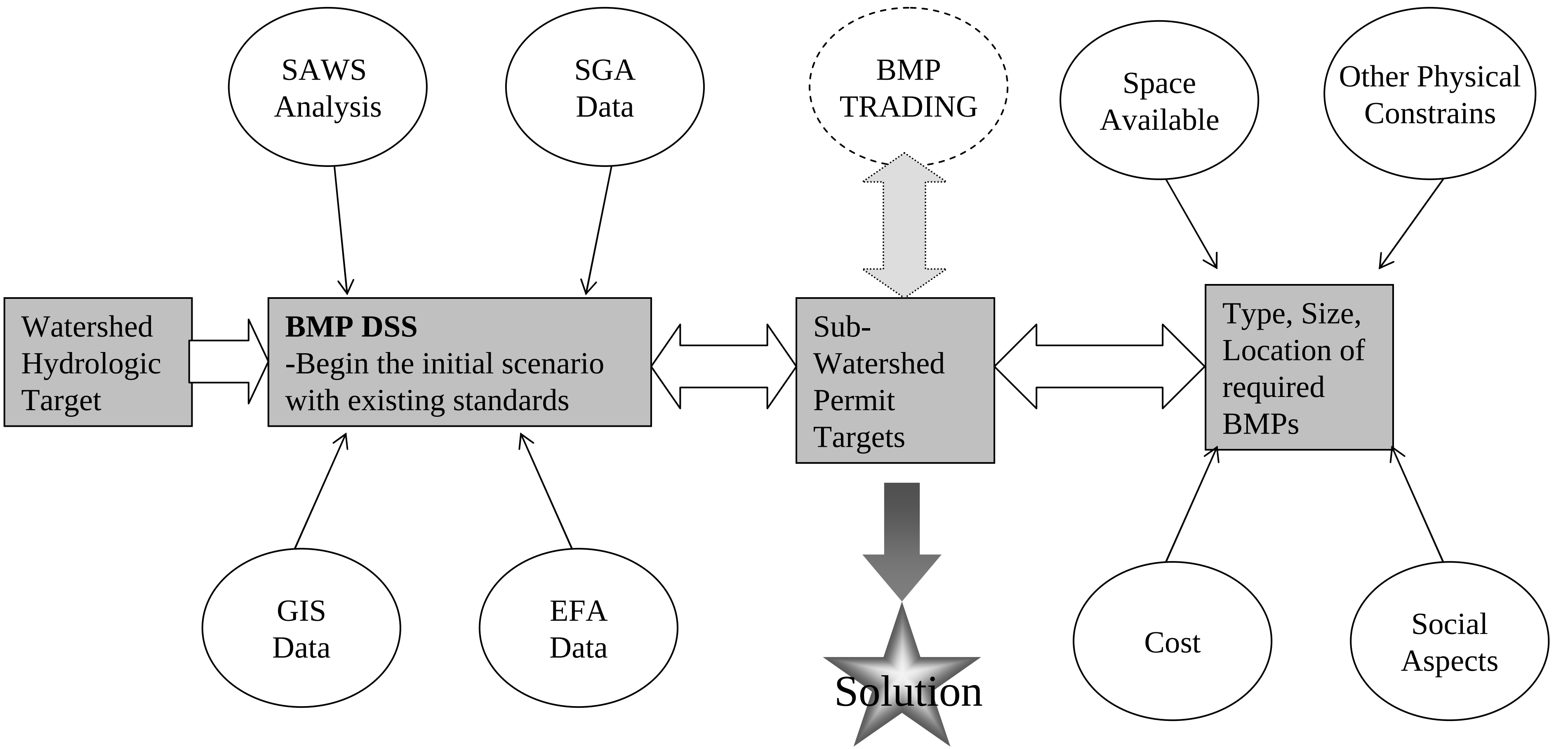
TETRA TECH, INC.



# BMP Tool Objectives:

- Develop a framework for evaluating BMP effectiveness at the watershed, subwatershed and parcel scales
- Take advantage of existing P8 dynamic model
  - Used in development of hydrologic targets
- Evaluate stormwater improvements using FDC
- Create a tool that DEC can use in-house

# Stormwater BMP DSS



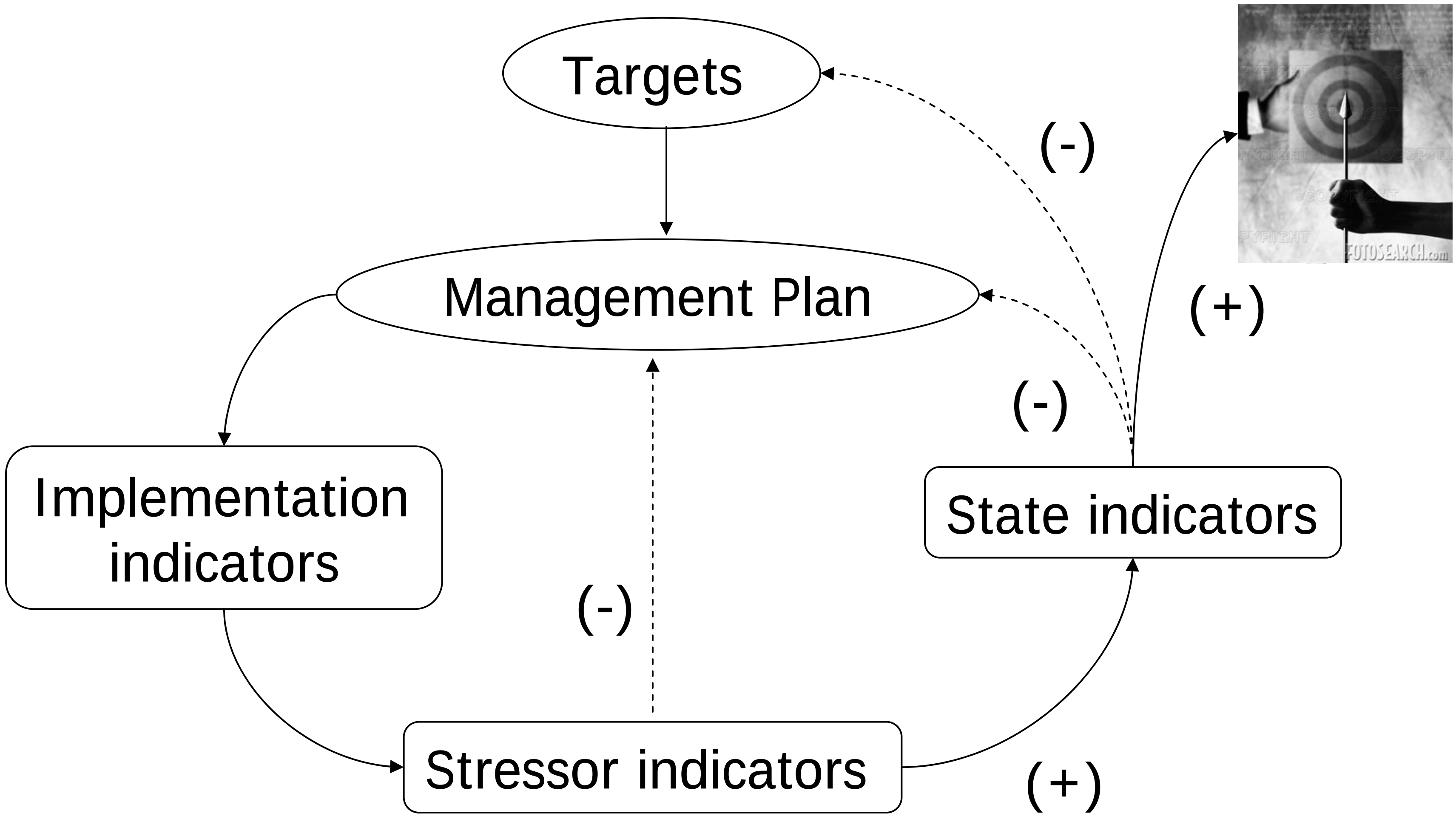
# Watershed-Wide Stormwater General Permits

- Output from the DSS BMP Tool
- The permit will regulate:
  - Upgrade of existing permitted sites
  - Upgrade of existing un-permitted sites as necessary to implement targets
  - New discharges, expansions, redevelopment

# Monitoring

- BMP Implementation
- Stream flow and precipitation monitoring
- Geomorphic assessments
- Macroinvertebrate and fish sampling

# “Adaptive Management” Approach will be Utilized:



# Questions???